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ROLE OF ORIENTATION REFERENCE SELECTION
IN MOTION SICKNESS

Semiannual Status Report
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(NASA-CR-181393) ROLE OF ORIENTATION
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SUMMARY OF PROPOSAL

Previous experiments with moving platform posturography have shown that different people have varying abilities to resolve conflicts among vestibular, visual, and proprioceptive sensory signals. In particular, there is one class of subjects with a vestibular disorder known as benign paroxysmal positional vertigo (BPPV) who often are particularly sensitive to inaccurate visual information. That is, they will use visual sensory information for the control of their posture even when that visual information is inaccurate and is in conflict with accurate proprioceptive and vestibular sensory signals. BPPV has been associated with disorders of both posterior semicircular canal function and possibly otolith function. The conceptual basis of the present proposal hinges on the similarities between the space motion sickness problem and the sensory orientation reference selection problems associated with the BPPV syndrome. These similarities include both etiology related to abnormal vertical canal-otolith function, and motion sickness initiating events provoked by pitch and roll head movements.

The objectives of this proposal are to explore and quantify the orientation reference selection abilities of subjects and the relation of this selection to motion sickness in humans. The overall objectives of this proposal are to determine (1) if motion sickness susceptibility is related to sensory orientation reference selection abilities of subjects, (2) if abnormal vertical canal-otolith function is the source of abnormal posture control strategies and if it can be quantified by vestibular and oculomotor reflex measurements, and (3) if quantifiable measures of perception of vestibular and visual motion cues can be related to motion sickness susceptibility and to orientation reference selection ability.

SUMMARY OF PROJECT STATUS

Three test devices are required for the proposed experiments. They are (1) moving posture platform, (2) servo controlled vertical axis rotation chair with an independently controllable optokinetic stimulator, and (3) a two-axis rotation chair for the generation of pitch and roll motions. The first two devices are currently functional and are routinely used for both clinical and research testing. The third device is under development. The development of this two-axis rotator has been a major focus in the first year and will be described in more detail below.

The second focus was on experiments involving the perceptual feedback technique developed by Zacharias and Young (Exp Brain Res, 41:159-171, 1981). We have also initiated some preliminary experiments using bilateral ice water caloric stimuli on the moving posture platform. This technique may provide a useful tool for temporarily altering vestibular input to posture control, and may permit a simple measure of the relative contributions of visual and proprioceptive cues to posture control.

TWO-AXIS ROTATOR DEVELOPMENT

The two-axis rotator is a versatile, general purpose stimulator for vestibular and visual-vestibular interaction studies. It consists of two gimbals powered by rotary hydraulic actuators. The inner gimbal produces yaw axis rotations of the subject. The outer gimbal rotates the subject about a horizontal axis which passes through the subject's ears. Figures 1-4 show the device in different orientations.

We have been working on 4 projects related to the two-axis rotator in the past 6 months. These are (1) design of a chair/restraint system for subjects, (2) design and construction of a optokinetic (OK) projector and projection screen, (3) design of a DC servo controlled torque motor which will be interchangeable with either the yaw or pitch axis hydraulic actuators, and (4) selection of components for a video based eye movement recording and analysis system.

Chair/Restraint System

The object of the chair/restraint system is to hold the subject firmly and comfortably in position during motion of the two-axis rotator. The chair/restraint system shown in Figures 1-4 is partially functional, but is intended only as a mock-up used to work out the design principles for the final chair. Based on this mock-up chair, we have nearly completed the design for the final chair assembly. The chair will be adjustable along three axes within the inner gimbal. This adjustment will allow for positioning any subject at the center of rotation of the two gimbal axes. It will also allow for some degree of off-axis positioning of the head.

Optokinetic Projector

The optokinetic projector provides a full field visual stimulus to a subject seated in the two axis rotator. Visual field rotation is controlled by a small torque motor which drives a slit projector through gear reduction belts. The compact projector can be mounted either above or to the side of the subject's head. Mounting the projector above the head provides a visual stimulus moving about the subject's yaw axis. Mounting to the side of the head provides a vertical OK stimulus. Two different cylindrical screens, one horizontal and one vertical, provide the surface on which the images of stripes are projected. Preliminary tests showed that the original belt drive gear reduction system did not provide an adequately smooth stimulus motion. The belt drive has been redesigned to correct this problem, and is currently being modified.

Electric Torque Motor

There is a class of experiments where sustained constant velocities have proven useful in identifying vestibular reflex responses related to otolith function. These experiments involve rotating a subject at constant velocity about an axis tilted off of earth vertical. Subjects produce sustained horizontal eye movements under these conditions. Animal experiments have shown that these eye movements are the result of central processing of otolith responses.

Since this grant is interested in otolith function, and sensory integration of otolith, semicircular canal, and visual motion information, we have been designing a DC torque motor system which would permit constant velocity or very

low frequency rotational movements. The motor will be interchangeable with the hydraulic actuators that are currently in the two-axis rotator.

The preliminary design of this motor has been completed and is shown in Figure 5. The motor will have 120 ft-lb of torque, and will be able to deliver that torque at a peak velocity of 320 deg/sec. Higher velocities will be possible at reduced torques. The power supply, transformer, servo controller and motor have been ordered from Inland Motor Corp. The detailed motor housing design, fabrication, and assembly will be done by J.A. Design, Greensburg PA. This is the same company that built the basic two-axis rotator. The complete motor is scheduled for delivery in about 7 months.

Video Eye Movement System

Eye movements evoked by vestibular and visual system reflexes in our two-axis rotator will be three dimensional. In order to study these reflexes it will be necessary to record the eye movements in relationship to the stimuli which cause them. Original plans for using a search coil system, or differential IR reflection systems have been rejected in favor of a video based system. The video system consists of recording and analysis subsystems. The recording subsystem includes a monochrome camera, IR light source, time code generator, monitor, video genlocking system for synchronizing video and computer timing, and video tape recorder. The analysis subsystem consists of a frame grabber, time code decoder, and computer software for analysis of eye position from information from the video signal. Equipment for the recording half of the system has been specified and ordered. The analysis half is only partially specified at this time, and will be a major project for the coming grant year. The major pieces of recording equipment include a PULNiX TM440S 1/1000th second shuttered CCD camera with remote head, Datam 5300 intelligent time processor, and Gyr video tape recorder with freeze field playback capability. This system should provide clear images of the eye 60 times per second. Each video field would be marked with a unique code which is synchronized with the timing of data collected on the computer which controls the two-axis rotator.

PERCEPTUAL FEEDBACK EXPERIMENTS

In 1981, Zacharias and Young presented a method which allowed for the quantification of a subject's perception of rotation under the combined influence of visual and vestibular cues. In this technique, the subject has control over the rotational motion of the chair by adjusting a potentiometer. Subjects are seated in the vertical axis rotation test room with the potentiometer mounted on the arm of the chair. The output of this potentiometer is summed with a velocity command signal from a computer and this summed signal is delivered to the velocity command input of the chair's servo motor. The goal of the subject is to continuously adjust the potentiometer so that they feel like they are not moving. A "perfect" subject would be able to hold themselves stationary in space by adjusting the potentiometer so that its output was equal but opposite to the computer's command signal. "Real" subjects do not remain stationary because of the dynamics of their motion perception and motor reaction systems, and because of presumed imbalances in the vestibular receptors.

The rotation of the subject's chair and the visual surround can be independently manipulated. We have used 8 different sensory environments for our preliminary experiments. These include (1) chair rotation in the dark, (2) rotation of the visual surround with the chair stationary, (3) chair rotation with the visual surround velocity equal to the chair velocity, (4) chair rotation with a constant velocity surround, (5) chair rotation with the velocity of the visual surround equal to the chair velocity plus a constant, (6) chair rotation with a stationary visual surround, (7) chair rotation with a time delayed, earth referenced visual surround, and (8) chair rotation with a time delayed, chair referenced visual surround. Condition (2) is used to test the motor control dynamics of the subject. Conditions (1) and (3)-(8) represent a variety of sensory environments in which the subject is forced to deal with either accurate, inaccurate, conflicting, or absent sensory cues about their motion.

Since the last progress report, we have added the two sensory environments (7) and (8) listed above. Both of these add a time delay between chair rotation and the rotation of the visual surround. Time delays are of interest because of their potential to disrupt the coordination of reflexes associated with orientation control.

Nine subjects have been tested in a protocol which included tests of horizontal VOR function as well as the eight perceptual feedback tests. The goal of these preliminary experiments was to (1) gain experience with this technique, (2) verify the results of Zacharias and Young, (3) extend the results of Zacharias and Young by including a wider variety of sensory environments, (4) determine the consistency of results for individual subjects tested over time, and (5) look for correlations between VOR and perceptual feedback test results. These techniques will later be extended to the two-axis rotator, compared with results of moving platform posturography, and correlated with the results of vestibular and oculomotor reflex measurements and measurements of motion sickness susceptibility.

These preliminary experiments demonstrated the importance of control for extraneous motion cues during the perceptual feedback experiments. In particular we found that the auditory cues from the OK projector motor influenced the experimental outcome. For example, subjects exposed to rotations in the dark (test (1)) often drifted in one direction or the other during the three minute test. This was expected from the results of Zacharias and Young. Subjects tested with the chair referenced visual stimulus (test (3)) should also experience drift since the visual stimulus available to them does not give any absolute, or earth referenced visual information. However subjects tested in earlier experiments under condition (3) did not drift. Results from the same subjects tested while wearing an auditory masker (Sony Walkman tuned between FM stations to give an approximate white noise signal) showed the expected drift. This confirmed that they were receiving auditory motion cues. In addition to auditory masking, we are shielding a portion of the peripheral visual field of the test subjects so that they cannot see their legs, or the floor and ceiling of the test room.

Some of the data on the nine subjects tested has been analyzed. Results in a given subject were repeatable for the perceptual feedback test performed in the dark. This is shown in Figure 6 which plots the average drift in chair velocity for the nine subjects tested two different times. We also found that results of horizontal VOR tests were repeatable within subjects. Figure 7

shows the test-retest results of horizontal VOR bias measured during a 0.05 Hz rotation test. VOR bias is a measure of the average slow phase eye velocity over an integer number of stimulus cycles.

The article by Zacharias and Young suggested that the drift of the subject during the rotation in the dark, or the chair referenced vision test might be due to an imbalance in the encoded motion information coming from the two halves of the vestibular system in opposite ears. This is also the interpretation which is generally given to the presence of bias, or directional preponderance observed in tests of horizontal VOR function. We anticipated that there might be a correlation between the drift observed in perceptual feedback tests and the bias recorded in VOR tests. However we have not found any obvious correlation between these two measures in the subjects tested to date (Figure 8). It may be possible that normal subjects have too small a range of bias and drift to provide a reliable correlation. However the bias measured for a given subject does appear to remain consistent over time, as does drift. That is, the reliability of the measurement of these two parameters seems to be fairly good. This would argue that the lack of correlation between these two measures is real, and not an artifact of their limited range, at least in normal subjects. Testing additional subjects should be able to sharpen these conclusions.

Abnormal subjects with large biases determined from horizontal VOR tests will be selected from the clinical population within the Clinical Vestibular Lab. Testing subjects with larger VOR biases should make any possible correlations with the perceptual feedback experiments more evident.

BILATERAL CALORIC TEST DURING MOVING PLATFORM POSTUROGRAPHY

The caloric test is one of the traditional tests of vestibular function. It is usually performed with the subject in a supine position. In this position, the irrigation of the external ear canal with water above or below body temperature artificially stimulates the horizontal semicircular canal. This stimulation induces a feeling of rotation and horizontal plane VOR eye movements.

When the head is in an upright position, the caloric stimulus should theoretically stimulate the vertical semicircular canals. Since the vertical canals presumably contribute to the control of posture, we were curious about the effect of a caloric stimulus on posture control. If it is possible to effectively disrupt the normal input of vertical canal motion cues to the central nervous system using a caloric stimulus, this may give us a useful tool for exploring how the orientation control system behaves in the presence of altered vestibular cues.

We have performed several simultaneous bilateral ice water calorics on normal subjects, and observed the effect on their posture control. The moving posture platform provides a good tool for these tests since it can be used to force the test subject to rely primarily on the vestibular system for posture control. With the subject's eyes closed to eliminate visual orientation cues, and with the platform sway referenced to the subject's anterior-posterior sway, minimal proprioceptive and visual motion cues are received. By eliminating these cues, the subject is forced to rely on vestibular input. If vestibular cues are disrupted using a simultaneous bilateral caloric stimulation, then the subject should not be able to control their posture, and they should fall.

Following a 12 second bilateral irrigation with 20cc ice water, subjects demonstrated profound posture control disturbances. The results for one subject are shown in Figure 9. These disturbances lasted about 2 minutes with a recovery to control values in about 4 to 6 minutes.

It is clear from these preliminary posture tests that we are able to disrupt vestibular cues necessary for posture control in normal subjects using bilateral ice water calorics. We intend to extend these experiments to test posture control under other sensory conditions. For example, it will be interesting to see if we are able to reveal underlying preferences for either visual or proprioceptive orientation cues in a given subject when their vestibular systems are disrupted. Perhaps subjects who prefer one sensory system over another when confronted with conflicting sensory cues are more susceptible to motion sickness.

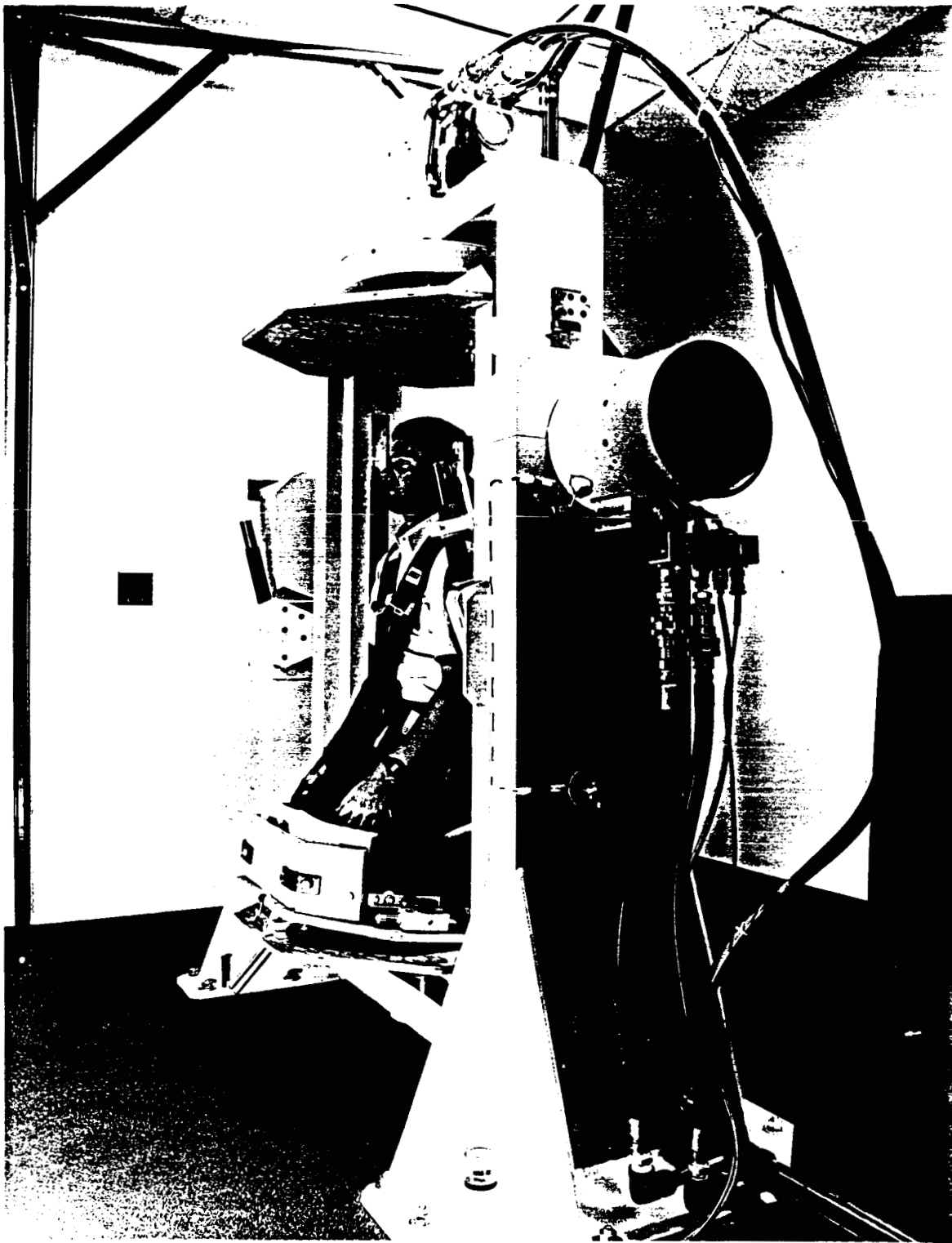


Figure 1. Two-axis rotation device

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Figure 2

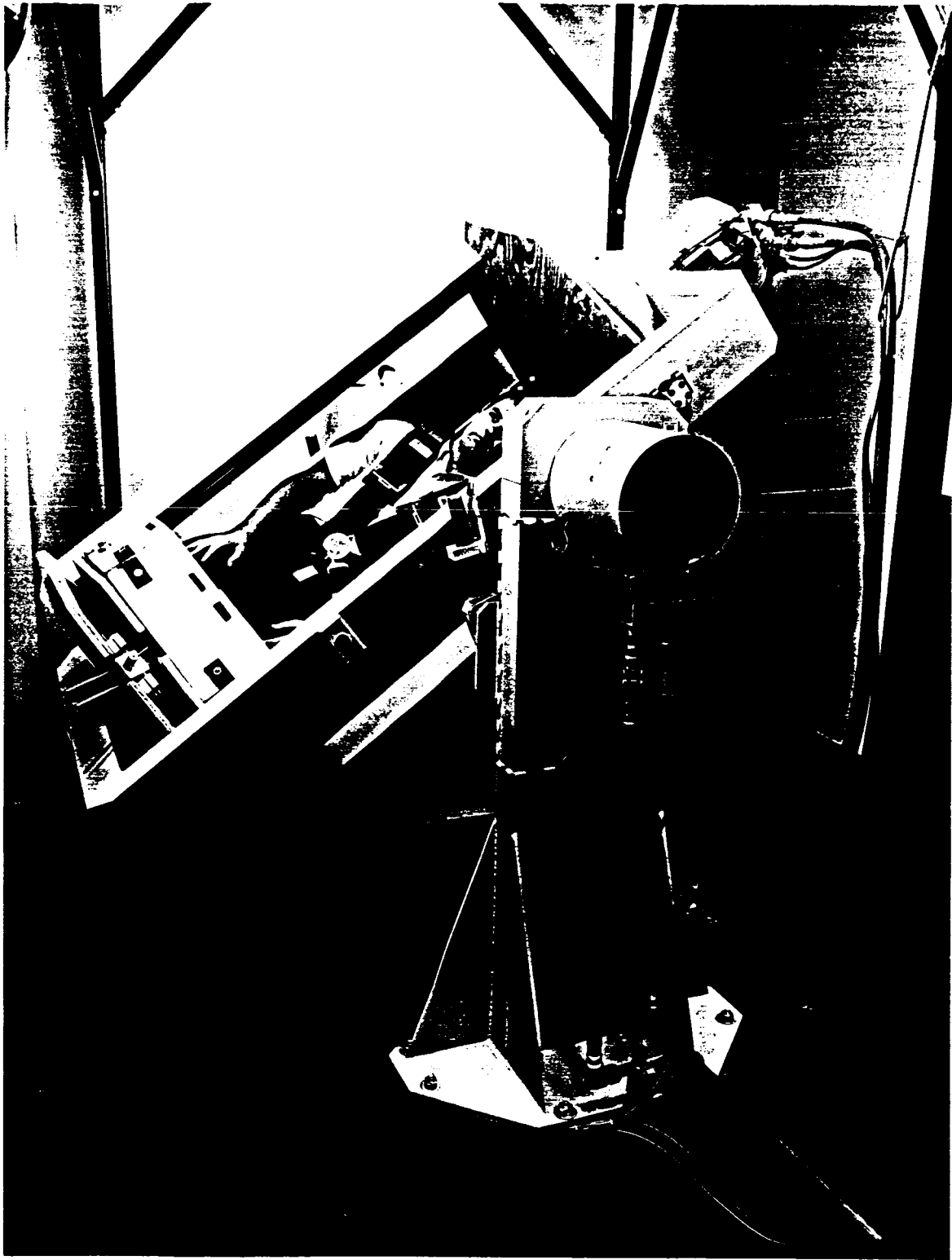


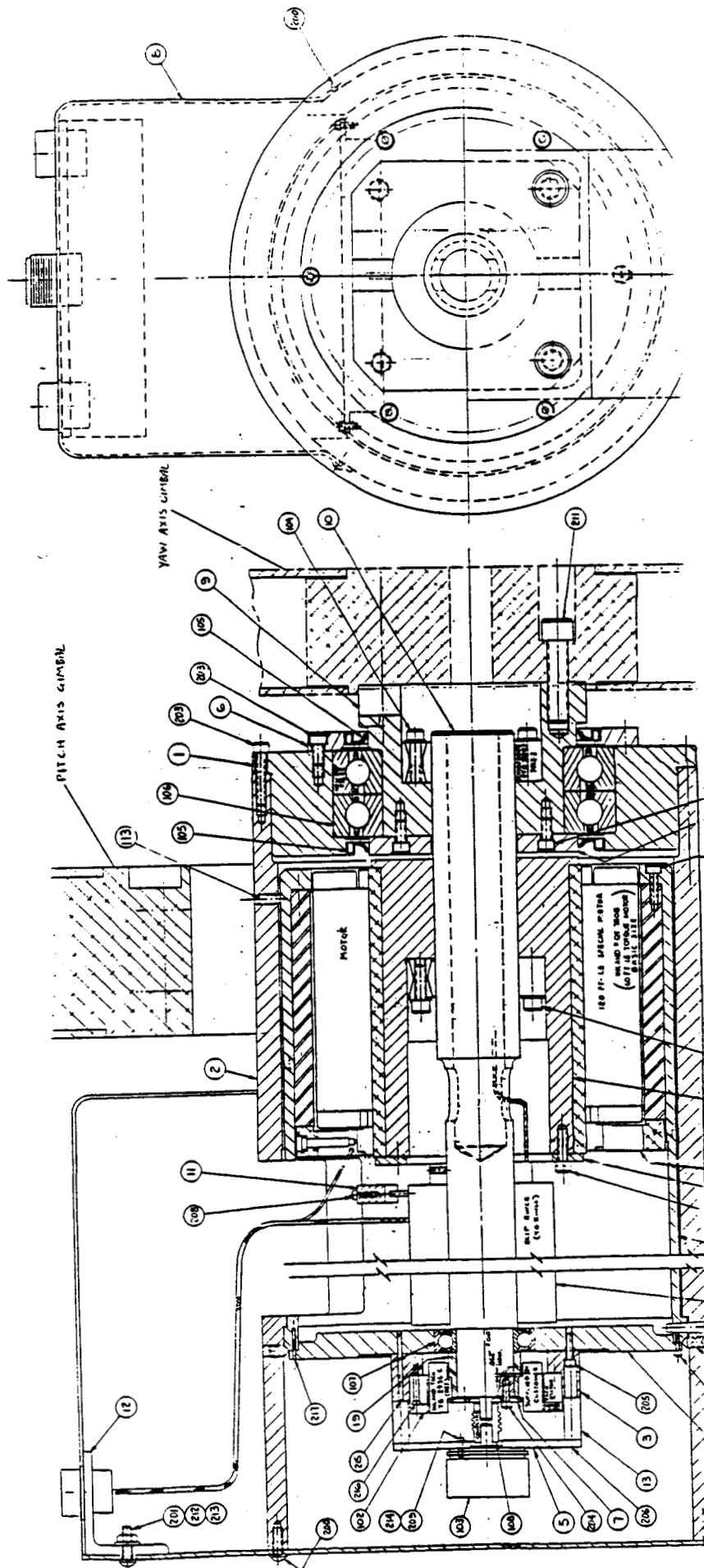
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Figure 4



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Figure 5. 120 ft-lb torque motor for two axis rotation device

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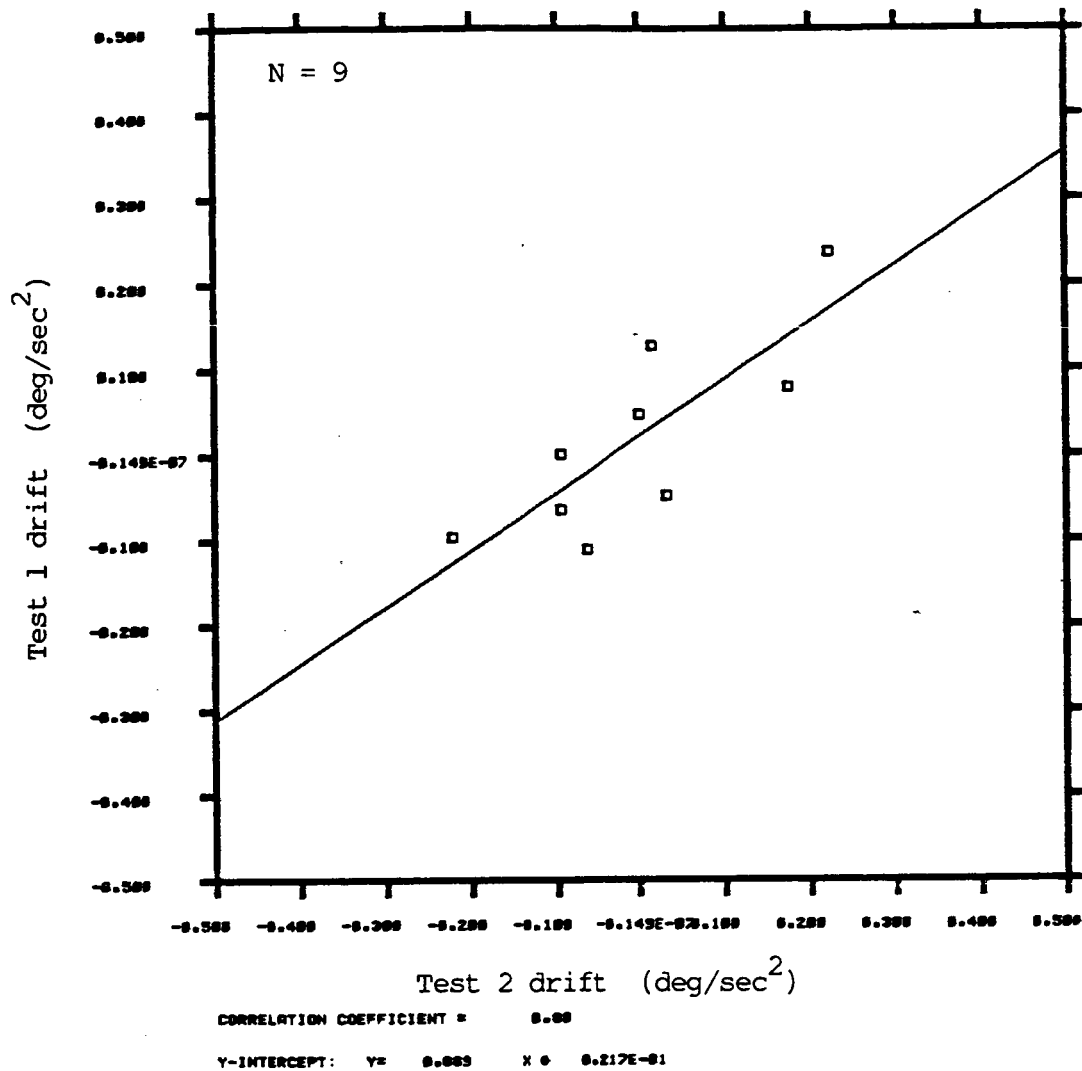


Figure 6. Test-retest of subject drift during rotation in dark perceptual feedback experiment.

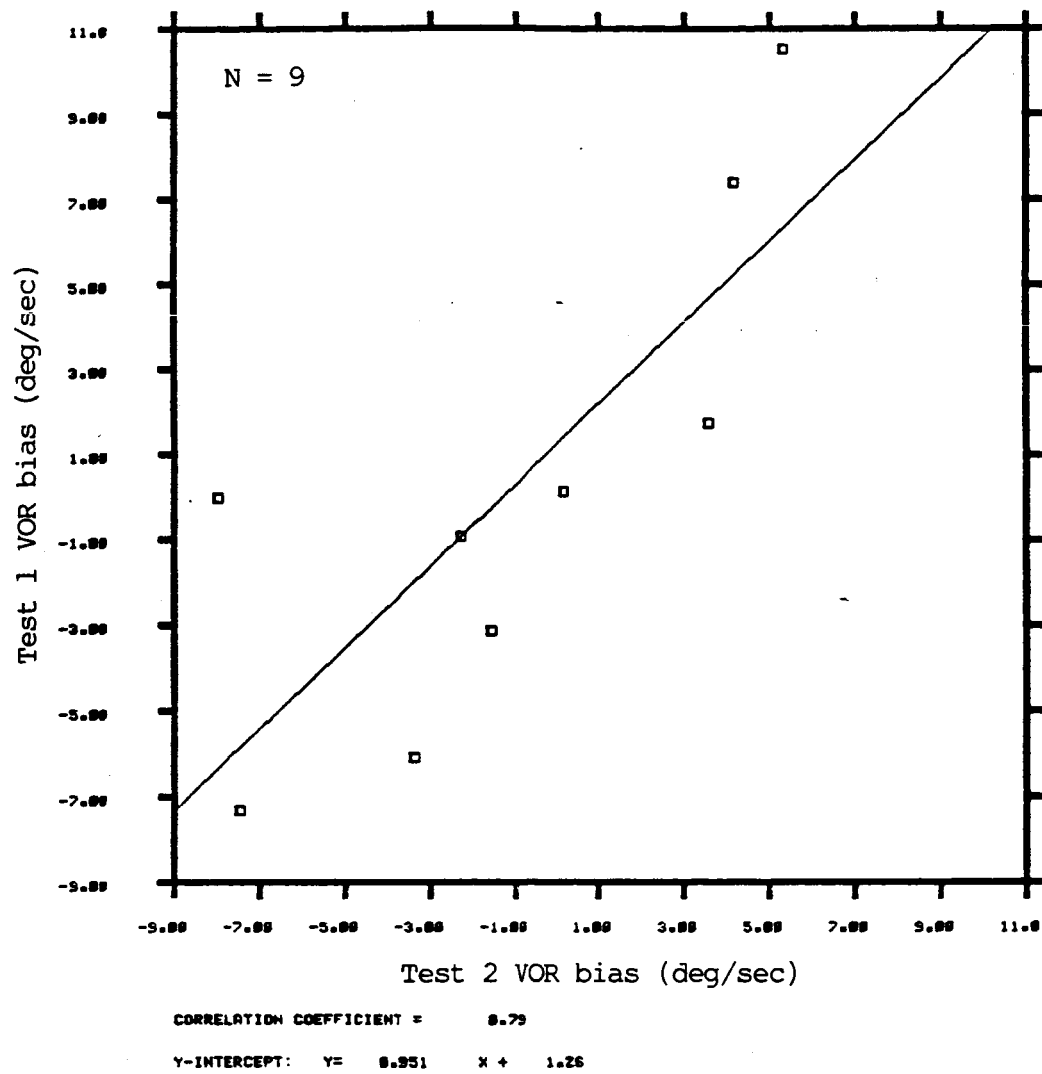


Figure 7. Test-retest results for 0.05 Hz VOR bias measure

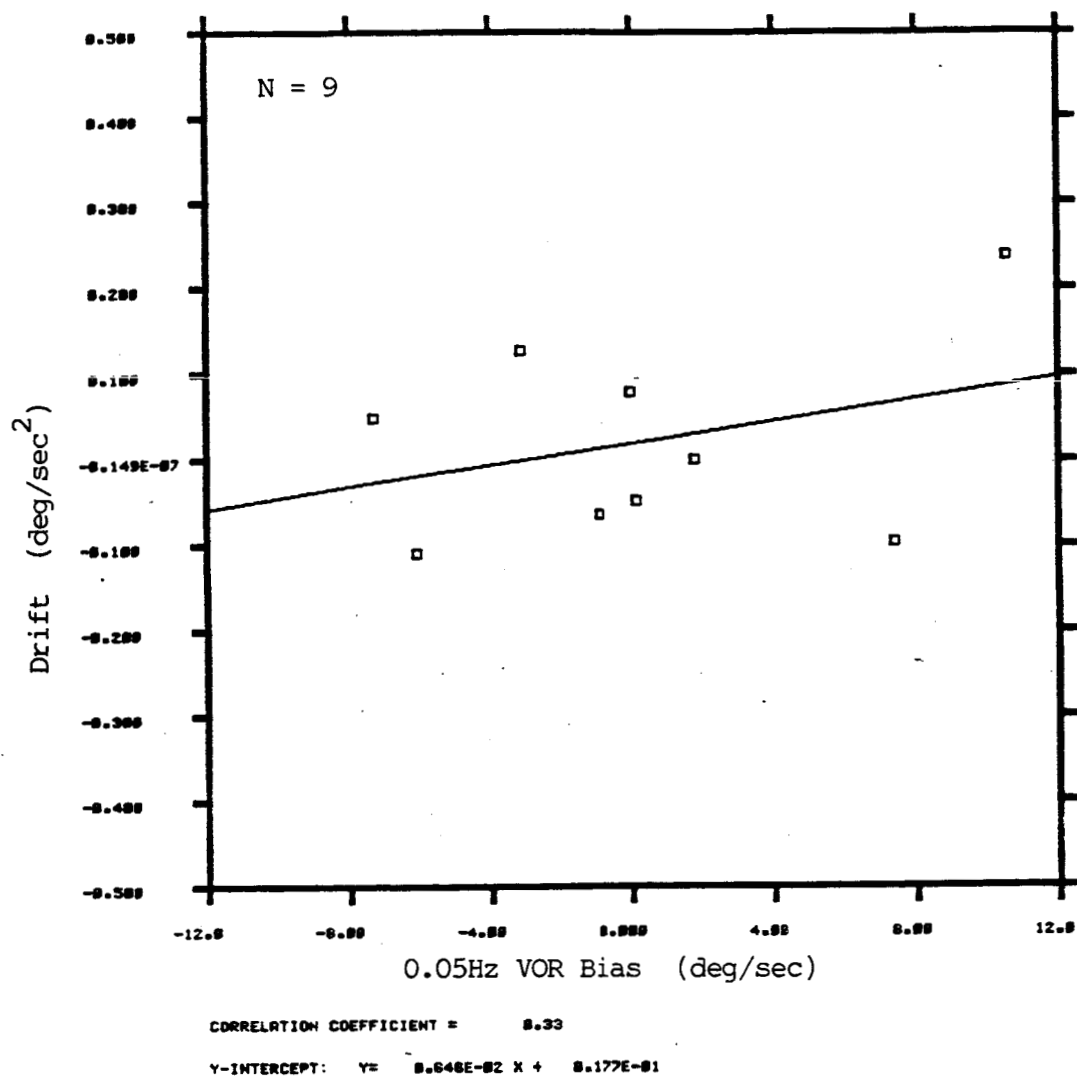


Figure 8. Poor correlation between drift during perceptual feedback test and 0.05Hz VOR bias.

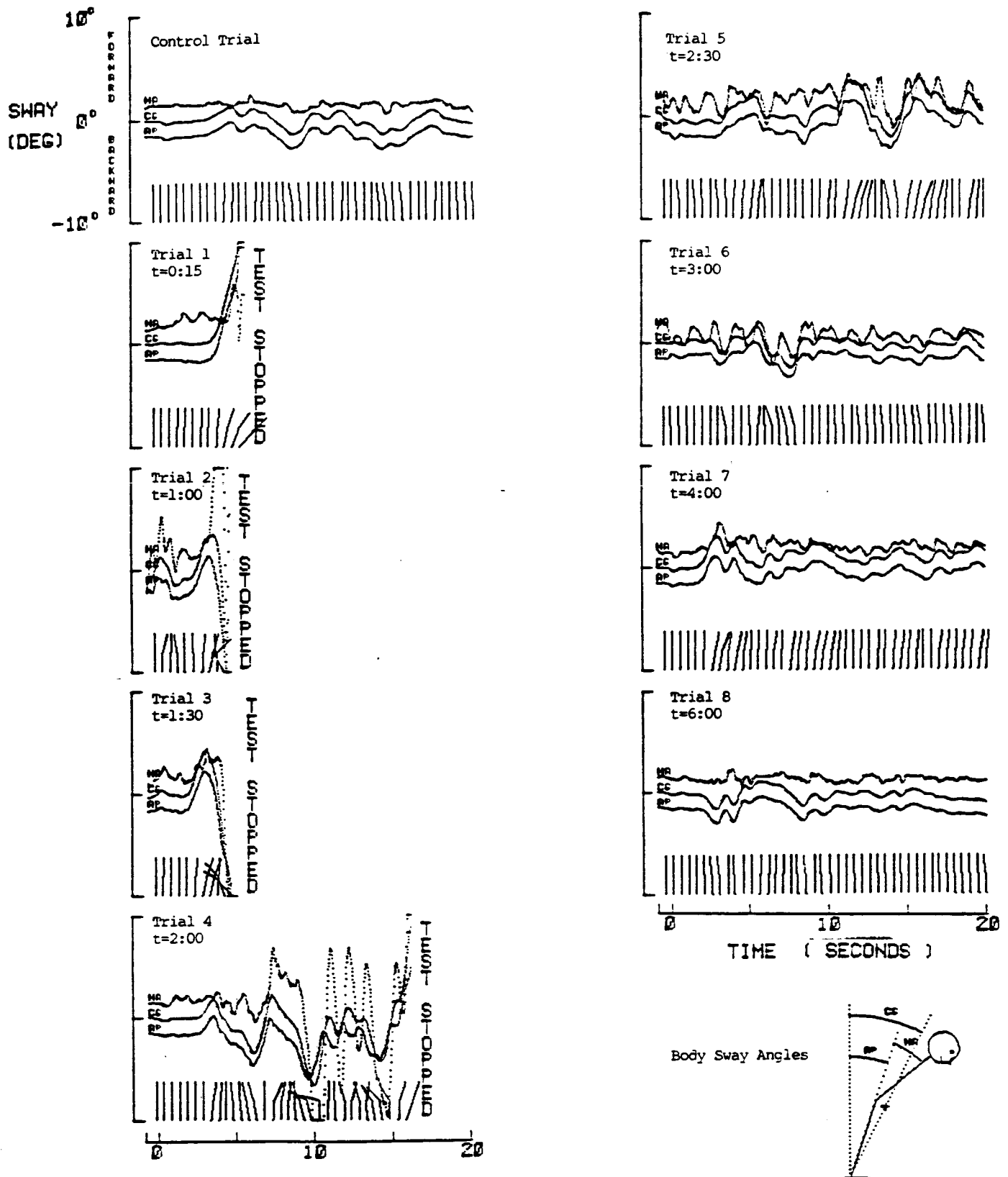


Figure 9. Posture test results following bilateral ice water caloric irrigations. Irrigations were 20cc ice water injected over 12 seconds beginning at t=0:00.